Selenium in Crops in the United States in Relation to Selenium-Responsive Diseases of Animals

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A map showing the regional distribution of Se concentrations in crops in the U. S. has been prepared, utilizing previously available and newly acquired plant analyses. The boundaries of areas on the map were based primarily on soil and geological information. In the Pacific Northwest, Northeastern United States, and the Southeastern Seaboard States, there are extensive areas where crops are generally low in Se. Selenium-responsive diseases in livestock are most likely to occur in these areas. In a very extensive area in the west-central U. S., the Se contents of crops are predominantly in the protective, but nontoxic, range of Se concentrations. Animal feeds grown in this area may be valuable additions to animal diets in the low-Se areas. Other parts of the U. S. are characterized by variable Se concentrations in plants.

Selenium-responsive diseases of livestock occur frequently in the United States and have been responsible for serious economic losses. White muscle disease (WMD) of lambs and calves is perhaps the most common of these disorders. The occurrence of WMD is related to the geologic nature of the soil parent material (*19*). There is also evidence that regional patterns of occurrence of WMD are related to regional differences in the Se concentration of feed crops (*3*).

In the U. S., there are also areas where Se toxicity has been evident in livestock. These areas have been studied extensively, and the distribution of geologic formations that form soils capable of producing high-Se plants has been established (*14*, *17*, *21*).

This report presents a map of the U. S. showing areas where the Se content of plants is adequate to protect animals from WMD, and areas where low levels of Se in plants may lead to Se-responsive diseases in animals, and describes how it was prepared. A similar survey of plant Se levels has been reported from western Australia (*9*).

Methods

First, a study was made of all the data on Se content of soils, rocks, and plants reported in connection with studies of Se toxicity in the U. S. Beeson (*6*) has compiled the sources of these plant data and summarized the factors affecting Se content of plants (*5*).

Next, plants from those areas not adequately characterized by the data accumulated during Se toxicity studies were collected and analyzed. Alfalfa was selected as the key plant for this sampling, because it will take up Se in levels representative of the available amounts in the soil (*10*) and it is grown widely in the U. S. Preliminary studies in Washington indicated that when alfalfa is growing on a soil having a low level of available Se, variations in variety and in stage of growth had little effect upon the Se concentration in the plants. Alfalfa growing on two different fields was sampled each year for three years. The Se concentration was less than 0.05 p.p.m. in all samples. Therefore, low-Se areas can be identified by determining the Se concentration in alfalfa growing in those areas, and variations owing to variety and stage of growth of alfalfa, or to seasonal weather conditions, are unlikely to confuse the identification of these low-Se areas.

Where alfalfa was not available, other forage crops were sampled, and in a number of cases, different forage species growing in mixed stands on the same soil were sampled. Analyses of the individual species growing in mixed stands of forages in low-Se areas showed that alfalfa generally contained slightly more Se than red clover, orchard grass, or timothy growing on the same soil. A very limited number of comparisons indicated that corn and soybeans tended to be similar in Se content to the alfalfa in the same area. Coastal Bermuda grass contained slightly more Se than alfalfa growing on the same soil type, but the number of these comparisons that could be made was quite limited.

The sites for plant sampling (alfalfa, where available) were selected to test the theory that a broad regional pattern of Se concentration in plants, based primarily on the nature of the soil parent material, exists in the U. S. Sites were selected to be typical of soil, physiographic, and geological areas, after studies of U. S., regional, and state maps of these characteristics. In addition, the regional distribution of samples collected in this study was designed to supplement rather than repeat the extensive Se analyses of plants obtained during earlier studies of the Se toxicity problem. Where several samples were taken to represent the same soil area, a minimum distance of five miles between sample sites was maintained.

At each sampling location, the tops were clipped from at least 10 different plants. The plant material was dried at 50° C. and the Se concentration in the plant determined fluorometrically (*1*).

Summary of the data collected during the earlier studies, plus those from about 1000 samples collected by the authors in 1963, 1964, 1965, and 1966, resulted in information on the Se content of plants in 480 counties in 46 of the 50 states. Louisiana, South Carolina,

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Reprinted from **AGRICULTURAL AND FOOD CHEMISTRY**, Vol. 15, No. 3, Page 448, May/June 1967

New Jersey, and Rhode Island were the only states not represented. The compilation of Williams, Lakin, and Byers (*25*) on Se in grains from the Great Plains area was used extensively, since it is one of the few studies related to Se toxicity where Se concentrations of less than 1.0 p.p.m. were reported.

The density of sampling ranged from counties with only one sample of known Se content to Lyman County, S.D., where Se concentrations of hundreds of samples have been reported through the years since 1933. The data were summarized by counties and plotted on a a national map (Figure 1). Data from counties where more than one-half of the crops analyzed contained less than 0.1 p.p.m. of Se are distinguished from those from counties where more than one-half the samples contained more than 0.1 p.p.m. of Se. The level of 0.1 p.p.m. of Se was selected as the differentiating value in Figure 1, since it seemed close to an upper limit of Se concentrations in the diets of cattle or sheep that have had WMD (*2*).

Data from counties where Se-accumulator plants containing more than 50 p.p.m. of Se had been obtained, but for which no data on the Se content of forage or feed crops are available, are also included in Figure 1. These collections of Se-accumulator plants indicate places where seleniferous soils or rock materials are present.

The data in Figure 1 show the general distribution of information on the Se contents of plants and give a generalized picture of the high- and the low-Se areas. To extrapolate this information to areas for which no data were available and to establish boundaries for different kinds of areas, the data on individual samples were studied in relation to generalized maps of soil or geological conditions. In particular, frequent use was made of the maps "Soil Associations of the United States" (*26*), and "Land Resource Regions and Major Land Resource Areas of the United States" (*4*). For information on the geology of various areas, the "Geologic Map of the United States" published by the U.S. Geological Survey in 1932, was consulted frequently.

Individual values for Se concentrations in plants also were plotted on large scale maps of the U. S., and tabulated by broad soil groups, physiographic regions, and soil parent materials. On the basis of these tabulations, the most suitable delineations for a U. S. Map appeared to be: I, areas where more than 80% of the crops contained less than 0.05 p.p.m. of Se; II, areas where more than 80% of the crops contained less than 0.10 p.p.m. of Se; III areas where the Se content of crops was variable with both low and adequate Se levels fairly common; and IV, areas where more than 80% of the crops contained more than 0.10 p.p.m. of Se.

The limits of these delineations were adjusted to coincide with boundaries of soil associations or geological areas wherever possible. When a soil association area was not represented by any analyzed plant samples, the area was classified with sampled areas to which it was most closely related in terms of soils and geologic materials.

In a few places where distinct changes in the Se content of sampled plants could not be related to soil or

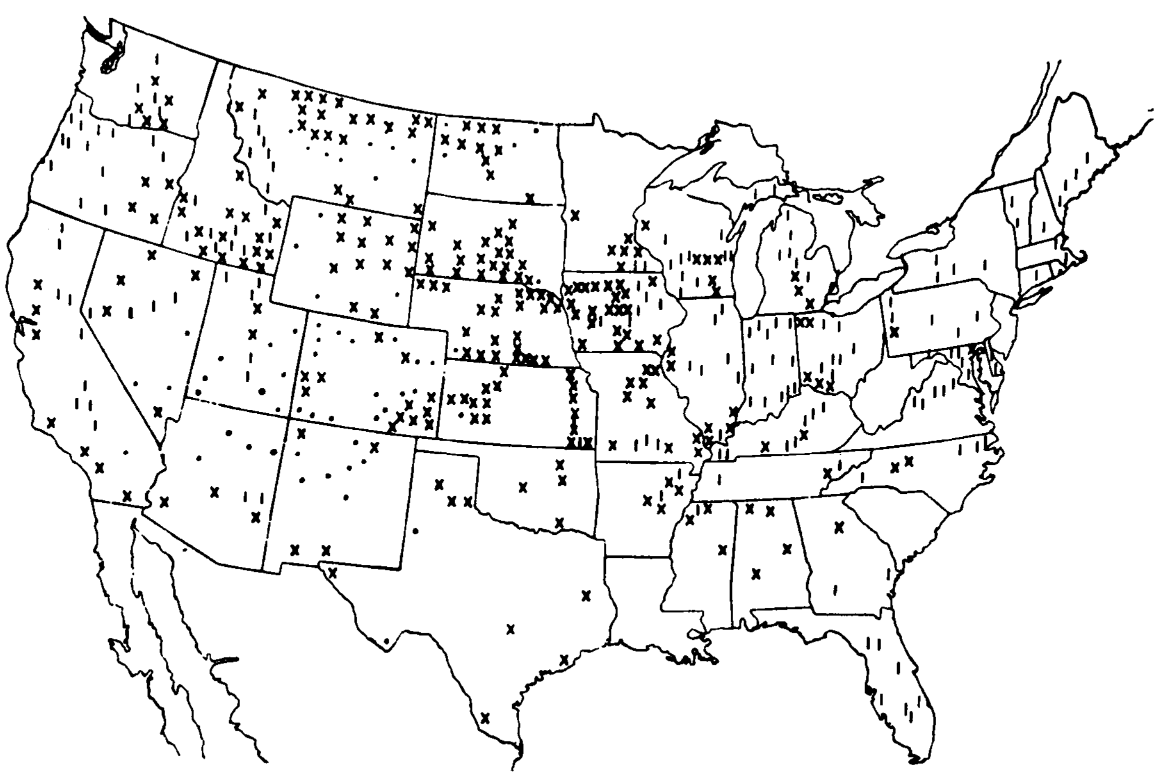


Figure 1. Locations and classification of counties where plants were collected for Se analyses.

|. Counties where over one-half of crops sampled contained less than 0.1 p.p.m. of Se
×. Counties where over one-half of crops sampled contained more than 0.1 p.p.m. of Se
●. Counties where Se-accumulator plants containing more than 50 p.p.m. of Se have been collected, but no data on forages or grains are available

geological changes, the boundaries were placed solely on the basis of data on Se content of plants.

With this procedure for mapping, there were unavoidable differences in the degree to which the classification of different places was supported by analytical data. In general, however, the areas where the production of feed and forage crops is most intensive were sampled in greater detail than were nonagricultural areas.

Results and Discussion

The recognizable areas producing plants having distinctive ranges of Se concentration are shown in Figure 2, along with the summarized plant data for each delineated area. Although the Se content of plants in some parts of the U. S. is variable, there are broad areas that can be defined as producing plants having very low, low, or adequate Se concentrations. The pattern of these areas appeared to be related to the geology of the soil parent material, with some modifications due to the effect of kind of soil profile development upon the availability of total soil Se.

The Se-Adequate Area. In Area IV, over 80% of the plant samples collected contained more than 0.1 p.p.m. of Se. These plants should provide animals with sufficient Se.

A major unifying feature of Area IV is the general distribution of sedimentary rocks of Permian, Triassic, Cretaceous, and Tertiary Age, or of materials transported from these rocks, in the soil parent materials. The origin and distribution of Se in these sedimentary rocks have been studied extensively (*14*). In the eastern and southern parts of Area IV, materials derived from the sedimentary rocks of the Plains States have been incorporated into the soil parent material through the action of flowing water, wind, and glacial ice sheets. The building of the Gulf Coastal Plain from sediments carried south and east from the Great Plains evidently involved a major spreading of Se over the aggrading land surface.

Materials from the sedimentary Cretaceous and Tertiary rocks of the Northern Great Plains were transported by glacial ice and by wind to many parts of Area IV occupying western Minnesota, western Iowa, and northern Missouri (*20, 22*).

Although Area IV contains places where Se toxicity in farm animals has been reported, the feeding of cultivated grain and forage crops does not appear to constitute a major cause of Se toxicity. The ingestion of Se-accumulator plants by range animals appears to be the major cause of acute Se toxicity in this area. Consumption of range grasses or, in a few cases, grains, may lead to chronic Se toxicity in animals in localized parts of Area IV. These places are most likely to be those where the soils are formed from Cretaceous shales.

A small fraction of the samples from this area contained less than 0.1 p.p.m. of Se. On the basis of relationships of the geology and kind of soil formation to the concentration and plant availability of Se in soils (*15*), plants containing less than 0.1 p.p.m. of Se would most likely be found in mountainous areas where the soils are formed from igneous rocks, in sandy, acid soils of the Gulf Coastal Plain, and in parts of Iowa and Missouri where older rocks are thinly covered by materials transported in from the west.

The eastern boundary of Area IV follows the eastern border of the glacial deposits of late Wisconsin Age from the Canadian border to central Iowa, and then along the eastern edge of the loess deposits blown into southern Iowa from the Missouri River valley. It then follows the eastern edge of the Mississippi River flood plain to northwestern Mississippi. From northwestern Mississippi, the eastern border of Area IV is extended east to encompass the coastal plains of Mississippi and the limestone valleys and coastal plains of Alabama.

The western boundary of Area IV follows the Rocky Mountains from the Canadian border to northwestern Wyoming and then is extended to the south along the western edge of the watersheds of the Green and Colorado Rivers. It is extended westward through Nevada and California to include the Los Angeles basin and southern California.

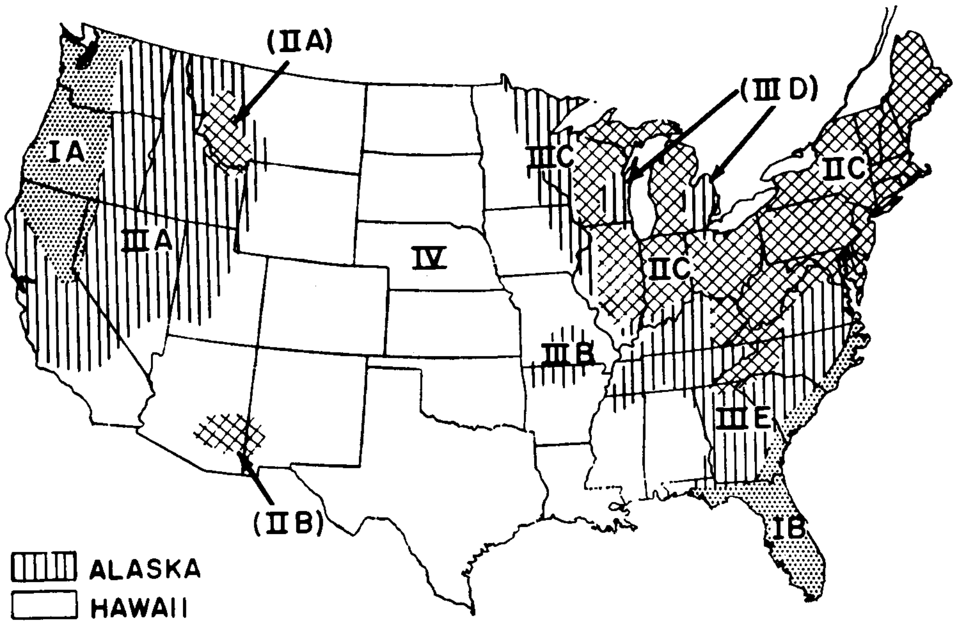
Areas Where the Se Concentration of Plants Is Variable. Areas where the Se concentrations in plants were found to be quite variable are designated with III on the map and generally are adjacent to Area IV.

AREA III A as shown in Figure 2 includes highly varied geological formations and soils. The California Coast Range from Los Angeles north to Eureka is included with this variable Se area, on the basis of the work of Lakin and Byers (*16*) showing moderate levels of Se in shales and vegetation in the foothills of these mountains. The young, alluvial soils in the first bottoms of the Sacramento and Kings Rivers produced alfalfa containing from 0.25 to 1.0 p.p.m. of Se, but, in general, forages from other parts of the central valley of California contained less than 0.10 p.p.m. of Se. The parts of Area III A in Nevada, Utah, southwestern Idaho, and southeastern Oregon include many closed basins filled with alluvium and lacustrine sediments interspersed with mountain ranges of volcanic rocks, granites, and sedimentary rocks. The northern part of Area III A includes the granitic Idaho batholith, plus plains and mountains of volcanic origin, and the Columbia basin. The soils of Area III A are predominantly neutral or alkaline, but some acid soils are present in the mountainous areas.

The Se that is so randomly distributed in Area III A may have at least four general types of origin. First, there are sediments of Cretaceous Age exposed by tilting in the California part of Area III A. Second, Eocene and Miocene sediments of fairly high Se content are exposed where recent volcanic deposits of low Se content (*8*) are deeply truncated by the Snake and Owyhee Rivers. Third, ancient Lakes Lahontan and Bonneville covered much of the intermountain basin area. These lakes may have received some runoff waters from seleniferous areas near their eastern margins. Fourth, seleniferous epithermal ore deposits are scattered through much of Area III A (*7*) and have been eroded to contribute Se to the soil materials in nearby valleys.

Selenium-accumulator plants containing more than 50 p.p.m. of Se have been collected in the Nevada, Utah, Oregon, and Idaho portions of Area III A.

With more detailed sampling and a larger scale map,



AREA	CROP	NO. OF SAMPLES	MEDIAN CONC.	FREQUENCY DISTRIBUTION (%) OF SAMPLES WITH Se CONCENTRATIONS (ppm) OF: <0.01 to 0.05	0.05 to 0.10	0.10 to 0.50	0.50 to 1.0	1.0 to 5.0	>5
I A	FORAGES	69	0.03	81	15	4	0	0	0
I B	"	26	0.02	89	11	0	0	0	0
II A	"	14	0.05	50	36	14	0	0	0
II B	"	11	0.05	36	45	19	0	0	0
II C	"	187	0.05	65	31	4	0	0	0
III A	"	261	0.09	20	31	43	4	2	0
III B	"	14	0.05	57	14	22	0	7	0
III C	"	39	0.09	20	41	26	13	0	0
III D	"	27	0.10	26	18	49	7	0	0
III E	"	79	0.06	50	23	22	5	0	0
IV	FORAGES	205	0.26	3	10	60	18	9	0
	WHEAT *	856	——	—— 9 ——		22	30	34	5
	FEED GRAIN *	262	——	—— 33 ——			22	38	7

* DATA FROM USDA TECH. BULL. 758. 1941.

USDA 1966

Figure 2. Generalized regional pattern of Se concentrations in crops

it may be possible to delineate some areas of consistent Se deficiency or adequacy within Area III A. For example, the Snake River plain north of the river in the vicinity of Gooding and Rupert, Idaho, and the Grande Ronde Valley of northeastern Oregon may be found to be Se-deficient areas with additional study. Other Se-deficient areas may be established in the higher elevations of mountains, such as the Raft River Range and in the Humbolt River Valley of Nevada. On the other hand, the Harney basin around Burns, Oregon, and the alluvial soils near the Snake River from Glenns Ferry, Idaho, to Hells Canyon may be areas where the Se content of plants is adequate for cattle and sheep. WMD has been reported in Area III A, but the frequency of these reports may be lower on comparable livestock numbers than in Area I A.

AREA III B occupies the Ozark mountains of Missouri and Arkansas. Although some forage crops containing very low levels of Se were collected in this area, there were also a few samples containing well above 0.1 p.p.m. of Se. The soils of Area III B generally are formed from limestones of Ordovician to Pennsylvanian Age. These limestones appear generally to be low in Se, but at least some parts of Area III B have received windblown sediments from the west. This erratic cover of transported material may have contributed some Se to the soil parent materials in parts of Area III B.

AREA III C includes soils formed from Pleistocene sediments (loess, till, and outwash) in the upper Mississippi Valley and western Great Lakes region. This area appears to have received some Se in glacial outwash during late Pleistocene time, but the deposition of Se in Area III C apparently was erratic, and forms of Se having a low availability to plants may be formed in the acid soils common in this area. The Tama soils of east-central Iowa generally appear to produce forages containing less than 0.10 p.p.m. of Se, and the soils formed from alluvium in the Mississippi River flood plain produce forages containing more than 0.10 p.p.m. of Se. There were no data on the Se content of plants in northern Minnesota, but this area is included with Area III C because it has received outwash from the west during late Pleistocene time.

AREA III D in the Great Lakes region includes two separated areas of soils formed from glacial deposits and lacustrine sediments. The Se in these areas may have been carried from the seleniferous ore bodies (*11*) of Ontario by glacial action. The segregation of fines by alluvial and lacustrine sedimentation also may have resulted in more Se in the soil parent material of Area III D than in those of the adjacent Area II C. WMD occurs in Wisconsin, Michigan, and Ohio, but the extent of the problem in the parts of these states included in Area III D is not known.

AREA III E is made up of regions in Kentucky and Tennessee where older sedimentary rocks, predominantly limestones, are common soil parent materials, plus the Piedmont and Coastal Plain regions of the South Atlantic States. In the Kentucky-Tennessee part of Area III E, plants collected in the valleys of streams draining limestone areas frequently contained more than 0.1 p.p.m. of Se. Plants from upland areas generally contained less than 0.1 p.p.m. of Se. More detailed study of this part of Area III E may permit the delineation of Se-adequate areas in the Tennessee and Ohio River valleys. Areas where plants have consistently low Se contents may, on further study, be identified in western Tennessee and Kentucky and on the Cumberland Plateau. The Se in this part of III E may have been a minor constituent of the limestones that became more concentrated in the soil parent materials as the carbonates were removed by solution. Forages collected from the Piedmont and Coastal Plain part of Area III E presented a highly variable pattern of Se concentrations, with samples containing more than 0.1 p.p.m. of Se and samples containing less than this amount occurring on the same farm. The Piedmont-Coastal Plain region includes sediments of Triassic and Cretaceous Age, and seleniferous sedimentary pyrites have been found in the region (*24*). The Se in this region may be the result of generally high levels of Se in the oceans during parts of the Triassic and Cretaceous Periods. The availability to plants of the Se in the soils of the Piedmont-Coastal Plain region would be expected to be relatively low owing to conversion of Se to iron-selenite complexes (*13*). Thus, although about 30% of the forage samples in Area III E contained in excess of 0.10 p.p.m. of Se, the area is one of predominantly low levels of Se in plants. Some WMD has been reported in the Kentucky, Tennessee, and South Carolina parts of Area III E.

Areas Where Plants Contain Low Concentrations of Se. Three distinct areas can be categorized as producing plants of low Se concentration (80% of all samples contained less than 0.10 p.p.m. of Se).

AREA II A occupies the valleys and slopes of the Beaverhead, Big Hole, and Bitteroot river watersheds, and the upstream (southeastern) part of Clarks Fork watershed in Montana. The soil parent materials of Area II A are mostly derived from granites and very old metamorphic rocks. The soils range from acid to alkaline. WMD has been a serious problem on many cattle ranches in Area II A.

AREA II B consists of soils formed on materials derived from Tertiary volcanic rocks in the White Mountains and their foothills of Arizona and New Mexico. It extends to the west along the Salt River Valley to Phoenix, Ariz. Apparently, the Tertiary volcanic rocks of this area were very low in Se, since if Se were present in the soils, it would be relatively available to plants under the alkaline soil conditions prevalent in Area II B (*15*).

AREA II C covers large parts of Wisconsin, Illinois, Indiana, Michigan, and Ohio, and all of West Virginia, Maryland, Pennsylvania, New York, and New England. This area extends into the southeastern states along the Allegheny, Blue Ridge, and Smoky Mountains and the Appalachian Plateau. The soil-forming materials of the region are derived primarily from old sedimentary rocks. These rocks were laid down prior to the period of selenization of the area just east of the Rocky Mountains. Much of the northern part of Area II C has been covered at least once by glacial ice sheets that moved in a north-to-south direction. It appears that these ice sheets generally reworked rock materials low in Se and carried relatively little Se into the area from the ore bodies of eastern Canada. In addition, the area generally is covered with acid soils, and the Se that is present may be relatively unavailable to plants. Several samples of corn and soybeans collected in Area II C contained less than 0.1 p.p.m. of Se, and Williams, Lakin, and Byers (*25*) report very low Se concentrations in wheat samples from this area. WMD has been reported in many states in this area, and the incidence of Se-responsive diseases in livestock and poultry in the area might be even higher except for the importation of animals feeds from Se-adequate regions.

Areas Where Plants Contain Very Low Concentrations of Se. More than 80% of the forage samples collected in an area in the Pacific Northwest and in another area in extreme southeastern U.S. contained less than 0.05 p.p.m. of Se. The median Se concentration in forages in these two areas was less than 0.03 p.p.m.

AREA I A has as its southern boundary a line from the Carson River Valley of Nevada northwest across the Sierras and the Sacramento River Valley to the Pacific Ocean near Eureka, Calif. From the Carson Valley, the eastern boundary of Area I A extends almost due north to Lakeview, Ore., and then to the east of the Deschutes River Valley of Oregon. From central Oregon northward, the eastern boundary of Area I A tends to parallel the eastern foothills of the Cascades.

Most of Area I A is covered by recent volcanic deposits, and the soils are formed on these deposits or on materials transported from them. The Se content of the recent volcanic deposits of Area I A is very low (7), and the low level of Se in the soil parent material appears to be the primary factor responsible for the very low Se concentrations in the forages grown here.

WMD is a very serious problem to livestock producers in Area I A. The etiology of the disease in Oregon has been described by Muth (*18*).

AREA I B occupies most of Florida, plus the lower coastal plain and tidewater sections of Georgia, the Carolinas, and Virginia. The soils of the area are formed from coastal deposits washed from a highly weathered land mass, and they are acid and poorly drained. A low level of Se in the soil parent material, plus low availability to plants of any Se that is present, appears to be responsible for the very low levels of Se in plants in Area I B. Since very little alfalfa is grown in Area I B, analyses of samples of grasses and clovers were used to classify this area.

Although the Se content of forages in Area I B is very low, little WMD has occurred in the area. This low occurrence of WMD probably is owing to presence of high levels of vitamin E in many animal diets in this area. Vitamin E has been shown to prevent WMD in some cases (*12*). This vitamin is normally high in green plants and declines in concentration in cured, stored plants. The long grazing season permitted by the mild weather characteristic of Area I B probably is responsible for higher levels of vitamin E in animal diets in this area than in the more northern parts of the U. S. A recent controlled test of the need for Se in cattle pastured on low-Se plants in Florida did not indicate a response to Se injections (*23*).

Se in Plants in Alaska and Hawaii. Analyses of wild grasses and shrubs from Alaska indicate that this state may be characterized as having plants of variable, but generally low Se concentrations. Upon more detailed study, plants from the Kenai Peninsula may be found to be consistently low in Se.

Research on Se in Hawaiian soils (*15*) indicates that the forages from this state very likely contain adequate, but nontoxic levels of Se.

Potential Use of the Map

The map (Figure 2) provides a partial basis for predicting the possibility of occurrences of Se-responsive diseases. In the northern part of the U.S., where the use of stored feeds containing low levels of vitamin E in animal diets is common, the Se-responsive diseases constitute a problem to livestock producers in Areas I A, II A, and II C. A localized pattern of occurrence of Se-responsive diseases may occur in parts of Area III A and in Areas III B, III C, and III D. In Area II B, the Se-responsive diseases are most apt to occur at the higher elevations where the grazing season is short and stored hay is used for wintering livestock. In areas I B and III E, high levels of vitamin E in animal diets, due to long grazing seasons, may minimize the need for Se, but if livestock management systems involving extensive use of stored feeds become common in these two areas, Se-responsive diseases may become more prevalent, especially in Area I B. Se-responsive diseases are much less apt to occur in Area IV.

The use of shipped-in grass and protein supplements is common in the dairy and poultry industries of the northeastern states. Where these feed constituents are grown in Area IV, they may be serving an important function in increasing the amount of Se in the diets of animals in Area II C. At the present time, interregional movements of animal feeds are primarily movements from feed-surplus to feed-deficit regions, without regard to the Se content of the feed ingredients that are shipped. The information in Figure 2 indicates that Area IV is the best source of feed ingredients for importation into low-Se areas, if a deliberate increase in the Se content of animal diets in low-Se areas is desired. However, the fact that a crop is grown in Area IV is not an absolute guarantee that it will contain sufficient Se to be useful for increasing the Se content of animal diets in which it is mixed with other components grown in low-Se areas. Figure 2 shows that there is a minimum of danger that crops grown in Area IV will result in Se toxicity when used as additions to animal diets in the low-Se areas.

The addition of Se compounds to the soil may, in the future, be considered as a method for increasing the Se content of crops grown for livestock feed. The map can be used to pick out areas where tests of this practice should be located, and to predict the probable extent of use of soil additions of Se, in case this method should become practical.

In any of its uses, it should be recognized that the map is generalized and that the density of sampling the plants of many parts of the U. S. was low. More accurate maps of individual states can be prepared, where desirable, through the use of more intensive sampling procedures.

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Received for review November 9, 1966. Accepted January 30, 1967.

PRINTED IN U. S. A.